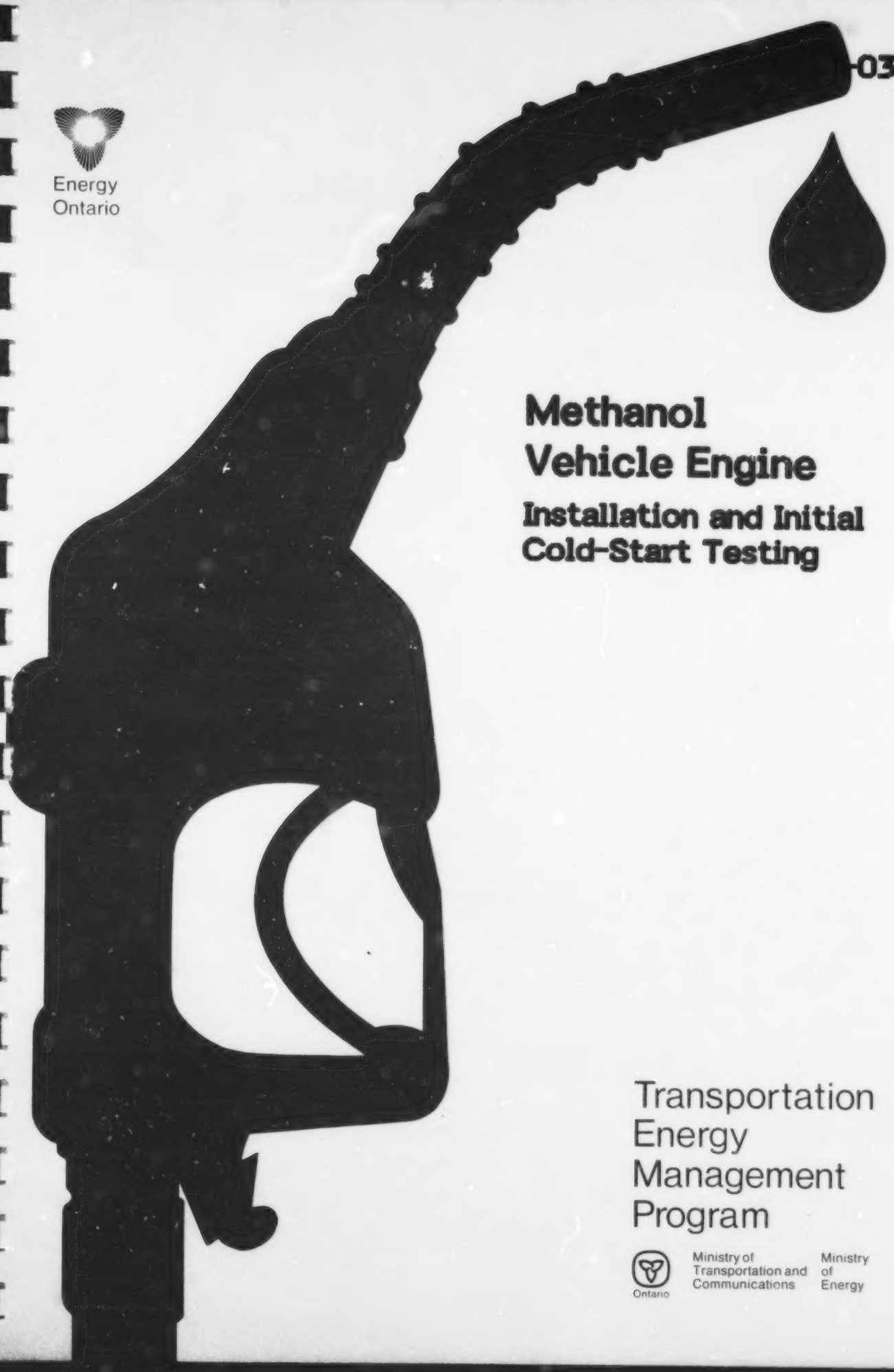
Energy
Ontario

03



Methanol Vehicle Engine

Installation and Initial Cold-Start Testing

Transportation
Energy
Management
Program

Ontario
Ministry of Transportation and Communications
Ministry of Energy

AF-86-03

Methanol Vehicle Engine Installation and Initial Cold-Start Testing

Prepared for:
D. Elliott
Project Manager
Automotive Technology and Systems Office

Prepared by:
M.F. Bardon
D.P. Gardiner
N.T. O'Brien
V.K. Rao
O.P. Nijhawan
Department of Mechanical Engineering
Royal Military College of Canada

Published by:
The Transportation Energy Management Program (TEMP)

The Transportation Technology and Energy Branch
Ontario Ministry of Transportation and Communications
Hon. Ed Fulton, Minister
D.G. Hobbs, Deputy Minister

Ontario Ministry of Energy
Hon. Vincent G. Kerrio, Minister
D.M. Allan, Deputy Minister

Published without prejudice
as to the application of the findings.
Crown copyright reserved; however, this
document may be reproduced for non-commercial
purposes with attribution to the Ministry.

For additional copies, write:
The Editor, Technical Publications
Ontario Ministry of Transportation and Communications
1201 Wilson Avenue
Downsview, Ontario
Canada M3M 1J8

March 1986

Technical Report Documentation Page

MTC Report Number: AF-86-03	ISBN Number:	Other Document Number:	Date: Mar. 1986

Title: Methanol Vehicle Engine -- Installation and Initial Cold-Start Testing

Authors (name, title and/or organization):
M.F. Bardon, D.P. Gardiner, N.T. O'Brien, V.K. Rao, O.P. Nijhawan
Royal Military College of Canada

Published by:
The Transportation Energy Management Program,
Transportation Technology and Energy Branch, MTC

Client Group:

Participating Agencies:
Ontario Ministry of Transportation and Communications,
Royal Military College of Canada

Abstract:
A new cold chamber has been constructed to be used for cold-starting performance testing of full-size automobile engines. A 1.6 L Ford Escort engine designed for methanol fuel operation has been installed. Shakedown testing has been conducted in which the engine was successfully started at temperatures as low as -6°C on pure methanol.

Key Words: methanol engine, cold starting

Comments:

Distribution: by request

Copyright Status: Crown copyright

ABSTRACT

A new cold chamber has been constructed to be used for cold-starting performance testing of full-size automobile engines. A 1.6 L Ford Escort engine designed for methanol fuel operation has been installed. Shake-down testing has been conducted in which the engine was successfully started at temperatures as low as -6°C on pure methanol.

TABLE OF CONTENTS

	PAGE
ABSTRACT	ii
FOREWORD	v
1/ INTRODUCTION	1
2/ TEST ENGINE	3
2.1/ Basic Engine Details	3
2.2/ Principal Design Changes for Methanol Operation.	3
3/ COLD CHAMBER	5
4/ ENGINE MODIFICATIONS AND SPECIAL HARDWARE	10
4.1/ Basic Installation Package	10
4.2/ Carburetor Controls.	16
5/ INSTRUMENTATION AND DATA ACQUISITION	20
6/ TEST PROGRAM AND RESULTS	22
6.1/ Engine Wear-In	22
6.2/ Carburetor Calibration	22
6.3/ Engine Cool-Down Tests	23
6.4/ Cold-Starting Test Procedure	24
7/ RESULTS AND DISCUSSION	26
7.1/ Cold-Starting Performance of the Escort Engine	26
7.2/ Effect of Cranking Speed	28
8/ CONCLUSIONS	30
9/ REFERENCES	31
APPENDICES	32
Appendix A/ Design of a Cold Air Supply for the Escort Engine	33
Appendix B/ Microcomputer Control System Specifications	38

LIST OF TABLES

PAGE

1/ Effect of Oil Dilution on Cranking Speed 28

LIST OF FIGURES

PAGE

1/ Cold Chamber 6
2/ Schematic of Two-Stage Refrigeration Unit 7
3/ Refrigeration Unit 8
4/ Engine Mounted on Test Stand 11
5/ Starter Motor Mounted to Engine and Test Stand 12
6/ Radiator Mount and Exhaust 13
7/ Manual Control Panel 14
8/ Brass Carburetor Inlet Adapter 15
9/ Vernier Choke Position Indicator and Locking Mechanism 17
10/ Stepper Motor Choke Position Control. 18
11/ Stepper Motor Throttle Position Control 19
12/ Minimum Ambient Temperature at Which Starting Is Possible . . 27
A.1/ Schematic of Proposed Engine Air Supply Using Liquid Air Cooling. 34

FOREWORD

As part of the Transportation Energy Management Program administered by the Ontario Ministry of Transportation and Communications and funded by the Ontario Ministry of Energy, work has been conducted on a number of alternative transportation fuels.

Methanol is the most practical synthetic liquid fuel capable of eventually displacing conventional hydrocarbons and able to be made from resources abundant in Canada. The present project is the second in a series aimed at understanding some of the factors that affect the startability of methanol-fuelled engines at low temperatures.

1/ INTRODUCTION

The work described in this report was funded by the Ontario Ministry of Transportation and Communications (MTC) as OJT&CRP contract #33361. Its purpose was to provide the basic experimental apparatus needed to study the cold-starting and, ultimately, cold-running performance of a representative full-size automotive engine designed for operation on fuels mainly composed of methanol.

Earlier cold-starting work conducted at the Royal Military College of Canada (RMC) used a small two-cylinder spark-ignition engine [1,2] originally produced as part of an electrical generator set. The intention in the present work was to give, as nearly as possible, the same close control over the important variables under laboratory conditions as was possible in the earlier installation but using an engine which more faithfully reflected current automotive practice.

The 1.6 L Ford Escort engine was selected because of the extensive in-vehicle testing which it was undergoing in the USA and also at several Canadian agencies, including MTC. The results of tests at RMC would then complement fleet and individual vehicle tests on the same engine.

The engine concerned was part of a build of approximately 500 vehicles by Ford Dearborn. In the interest of economy it seemed reasonable at the planning stage of this project to purchase only the engine, rather than the entire vehicle. The budget and timetable were determined on that basis. This turned out to be a tactical error because the engine supplied was essentially extracted from the production line at the point where it would normally be installed in the vehicle. As a result, it was little more than a long block assembly plus those subcomponents that had been extensively modified for use with methanol. In addition to major components such as the starter, alternator, air pump, radiator, ignition coil, and air cleaner assembly, there were numerous essential smaller items missing, such as relays, hoses, exhaust emissions fittings, switches, etc. It required months and a vast effort on the part of Ford and RMC staff to correctly identify exactly which items were missing, determine which stock numbers applied to the particular engine supplied, obtain the items from the USA, then assemble the resulting jigsaw puzzle.

In retrospect, it would have been far less costly and time-consuming to purchase the entire vehicle and discard the unnecessary items. The error was due to differences between the purchaser's perception of what was ordered and the vendor's concept of industry practice. As a one-of-a-kind buy involving several organizations, the intended use was unique and not apparent to the supplier in the USA. Ford Canada was most helpful in remedying the situation once the results of the communication gap became

apparent. In the end, all the required items were obtained, but the program was delayed by about seven months.

The following sections describe the construction of the new facility, including a larger cold chamber, the engine installation, instrumentation and control system, and the shakedown testing conducted to determine the cold-starting performance of the engine using pure methanol. The initial testing was performed on neat methanol so as to provide a well-defined bench mark to which all future primed or blended fuels could be compared.

2/ TEST ENGINE

2.1/ Basic Engine Details

The engine selected is a production 1983 Ford Escort engine modified by the manufacturer for operation using methanol. Full details of the modifications are contained in Reference 3.

Specifications common to both gasoline and methanol versions of the engine are as follows:

- Displacement - 1.6 L
- Bore - 79.96 mm
- Stroke - 79.52 mm
- Type - overhead cam, compound valve, hemispherical combustion chamber
  - designation -- compound valve hemi (CVH)
- Induction System - one progressive two-barrel carburetor

2.2/ Principal Design Changes for Methanol Operation

The engine purchased is one of the 582-car build of June 1983 and differs somewhat from the original 1981 40-car build [3]. The following modifications were made to adapt the original gasoline engine for methanol:

- compression ratio of 11.8 (using pistons designed for the 1.3 L engine made by Ford in Europe);
- special distributor advance curve;
- chrome-faced top compression ring (wear resistant);
- special cylinder head gasket originally designed for turbo-charged engines (note use of baseline gasoline "fuel economy" camshaft in this otherwise high output (HO) engine configuration);
- nickel-plated fuel pump with methanol-compatible diaphragm;
- special early fuel evaporation (EFE) using a positive temperature control (PIC) heater installed between the carburetor and intake manifold (heater uses a different grid design and conductor material than the one used on gasoline engines);
- spark plugs two heat ranges colder to prevent preignition;
- crankcase oil specially formulated to be "methanol-compatible";

- a 740 model progressive two-barrel carburetor as used on baseline economy gasoline (not HO type), which is extensively modified for methanol by

  - complete recalibration of main, idle, secondary, and acceleration pump circuits to account for the lower calorific value of methanol; and

  - material changes due to the corrosive nature of methanol, including nickel plating of zinc body; change in float material from nitrophyl to acetal to prevent "sinking"; new compound Vernay Viton fuel inlet needle tip; and replacement of numerous parts with stainless steel or nickel-plated ones.

3/ COLD CHAMBER

Figure 1 shows the cold chamber constructed under this program. The interior floor space available is approximately 2.1 x 2.3 m with a 2 m overhead clearance.

The chamber was sized to allow for a second engine if needed in future, with adequate working space around both. It was built to make use of existing engine mounting rails embedded in the concrete floor of one of the Mechanical Engineering Department test cells.

Construction is of aluminum framing insulated with 15 cm of styrofoam insulation applied in two layers to eliminate direct metal heat paths between the interior and exterior. Aluminum door hardware and window fittings were specially fabricated for the installation.

The chamber makes use of an existing refrigeration unit previously constructed for cold-starting tests in a smaller chamber. Figure 2 is a schematic of the unit. Figure 3 shows the main components of the two-stage system.

The much larger mass of the new large chamber and its contents was expected to result in considerably longer cool-down times. To provide as much flexibility in testing as possible, rather than simply discarding the small existing cold chamber, the new installation was designed so as to allow the refrigeration unit to drive either chamber. This retains the advantages of the existing facility, mainly rapid cool-down, which allows considerable testing to be conducted in a short time period. To achieve this dual configuration, the refrigeration unit was modified so that a second evaporator located in the new test chamber runs in parallel with the existing low-stage evaporator. Valves allow either to be used as required. In principal, both could be driven simultaneously, but it is not certain that the refrigeration unit has adequate capacity for both at very low test temperatures. There would also likely be additional control valves required. To date, no attempt has been made to operate both chambers at once.

Minimum chamber temperatures achievable in previous testing were better than -60°C, and similar results are expected with the new unit. At present, the thermostatically controlled evaporator valve limits operation to about -30°C. This was adequate for the shakedown testing required under this program; however, a different evaporator valve will be installed for the lower temperature testing to be conducted in a subsequent program.

The quantity of air contained within the cold chamber is adequate for conducting cold-starting tests. However, the long-term plans for the

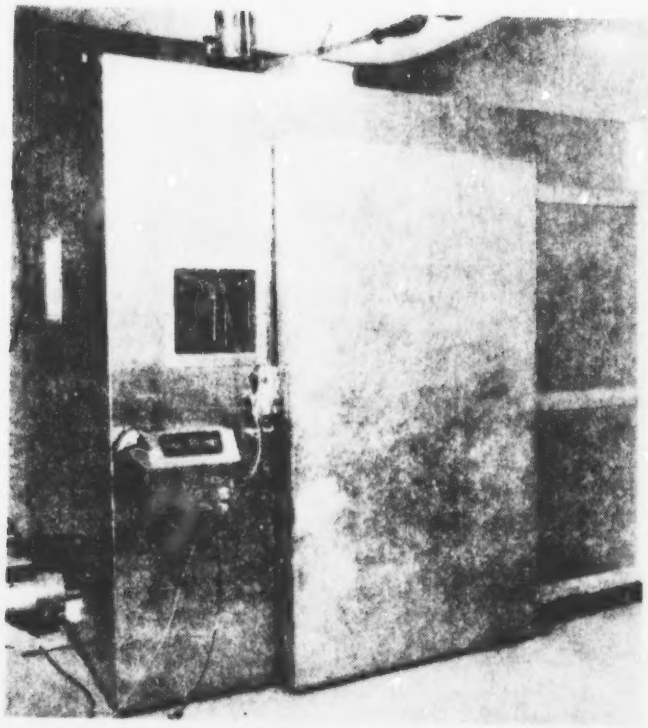


Figure 1/ Cold Chamber

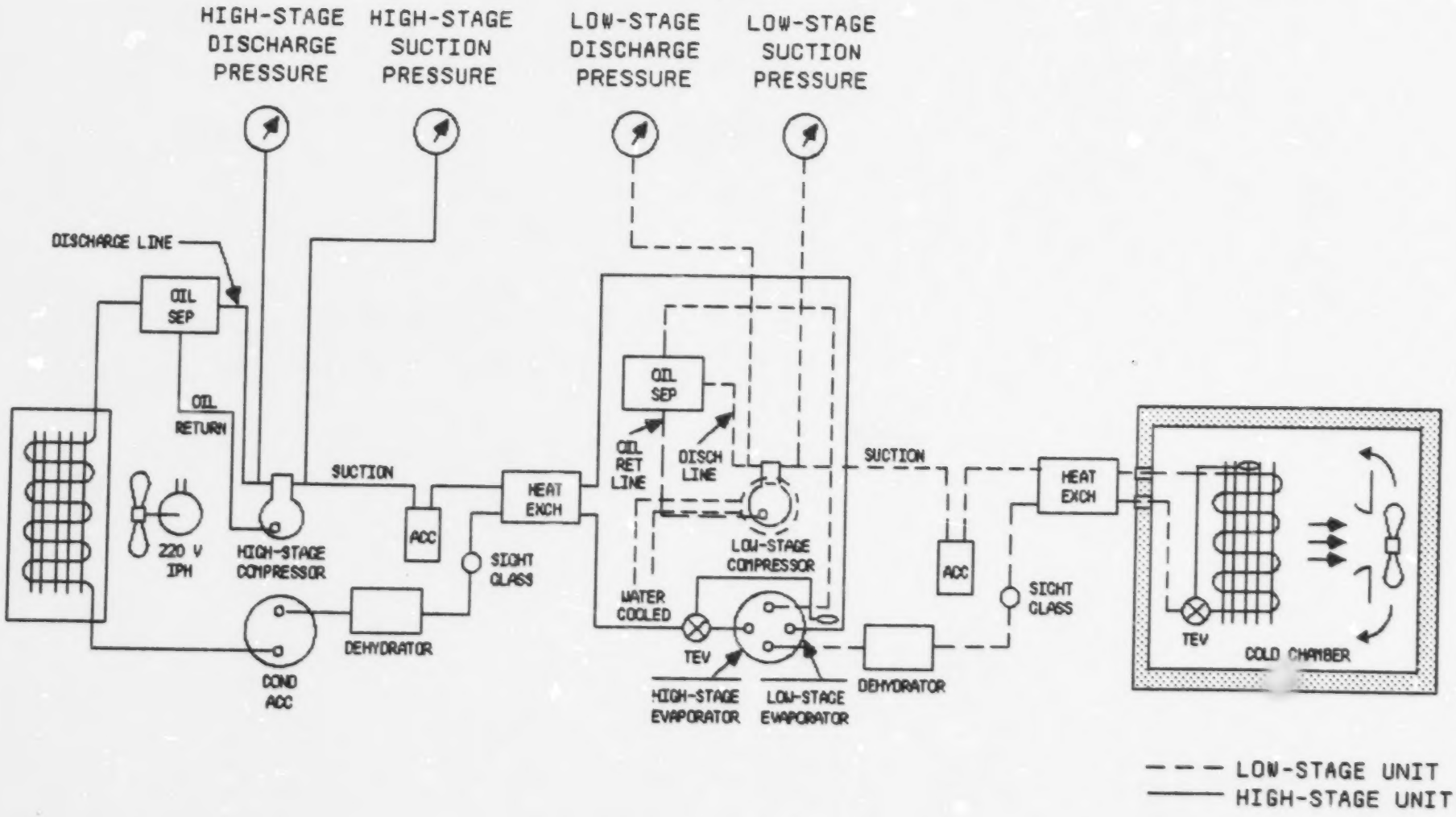
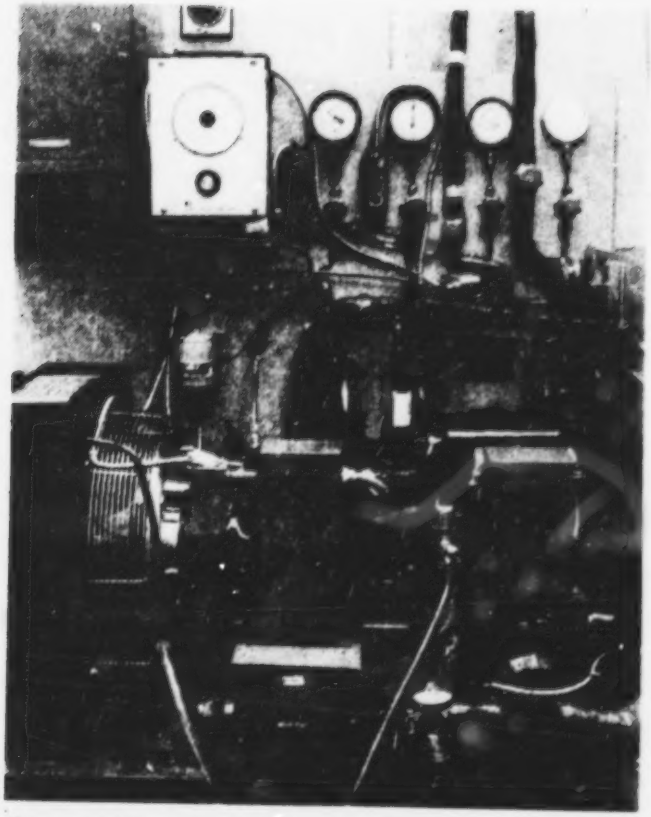


Figure 2/ Schematic of Two-Stage Refrigeration Unit



Separate parallel evaporators are located in each cold chamber.

Figure 3/ Refrigeration Unit

program involve warm-up and other cold operating trials which require a continuous supply of air at controlled low temperatures. Since the principal requirement in this project was to set up facilities needed for cold starting, only limited resources were available for studying the future requirements related to cold running. Nevertheless, a preliminary analysis was undertaken of a cold air supply system using liquid air. Since the Mechanical Engineering Department has a liquid air plant, such a system would be less costly and take up less laboratory space than the alternative of installing the large refrigeration unit needed to cool the quantities of air consumed by a running engine. The preliminary design calculations and sketches are included in Appendix A.

4/ ENGINE MODIFICATIONS AND SPECIAL HARDWARE

4.1/ Basic Installation Package

This engine is normally mounted transversely in the vehicle. It connects to frame and body members at a number of points, and numerous essential components are, in fact, mounted separately from the engine. To install the dismounted engine and all required ancillary components in the cold chamber, special provisions had to be made to take into account the missing frame, transmission housing, etc. The following are the main items fabricated for the basic engine installation:

- engine test stand (Figure 4);
- engine mounts with rubber insulators to allow longitudinal mounting of the engine in the test stand;
- starter mount to hold the starter as well as to position it properly so as to ensure correct pinion/ring gear engagement (Figure 5) (normally the starter bolts to and is aligned by the transmission housing);
- mount for stock radiator (Figure 6);
- exhaust piping with silencer and vibration-proof flexible couplings from the manifold through the cold chamber roof via a heat-resistant gland, then on through the roof of the test cell itself;
- mount and coupling to attach a dc generator to the crankshaft for use as a tachometer (Figure 4);
- an exterior control panel, including a manual fine-adjust cable-type throttle control plus oil pressure, temperature, and voltage gauges (Figure 7);
- a start-on-off linkage to replace the mechanical part of the mechanism normally located in the steering column of the vehicle, permitting use of the stock electrical ignition components;
- flywheel safety cover;
- adapter to allow the stock air cleaner assembly to be used in spite of the modifications to the choke system;
- adapter to allow the carburetor inlet to be fed through a large air box fitted with an orifice meter for measurement of airflow (Figure 8);
- two accessory panels to hold the items normally mounted to the fire wall or elsewhere, such as the voltage regulator, starter relay, exhaust gas recirculation (EGR) control, ignition coil, etc.

As well as these additional items, the stock exhaust header was modified to allow the exhaust pipe to exit the chamber directly from the exhaust port side of the engine. In the original configuration it passes beneath the engine because of to the transverse engine mounting in the automobile. Header pipe lengths were maintained unchanged so as to avoid changing the scavenging characteristics of the engine.

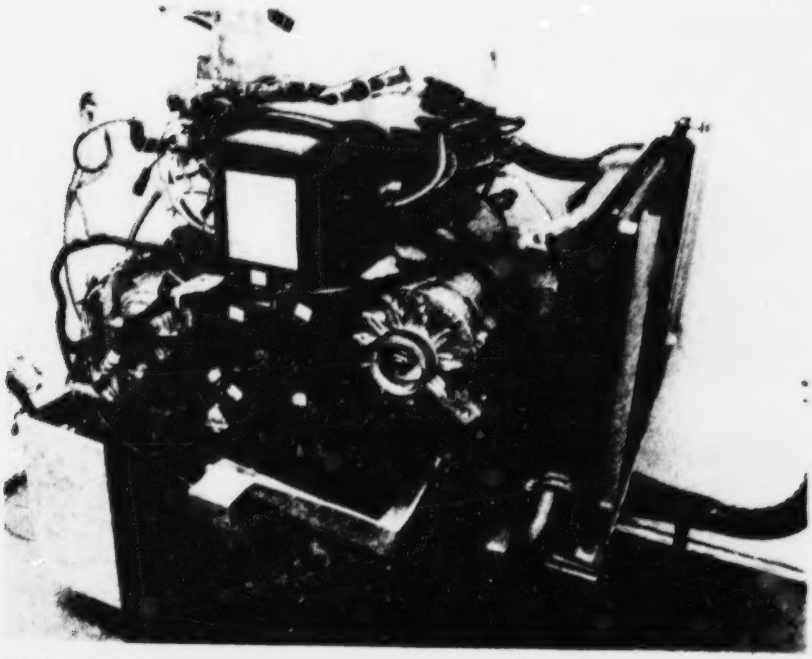
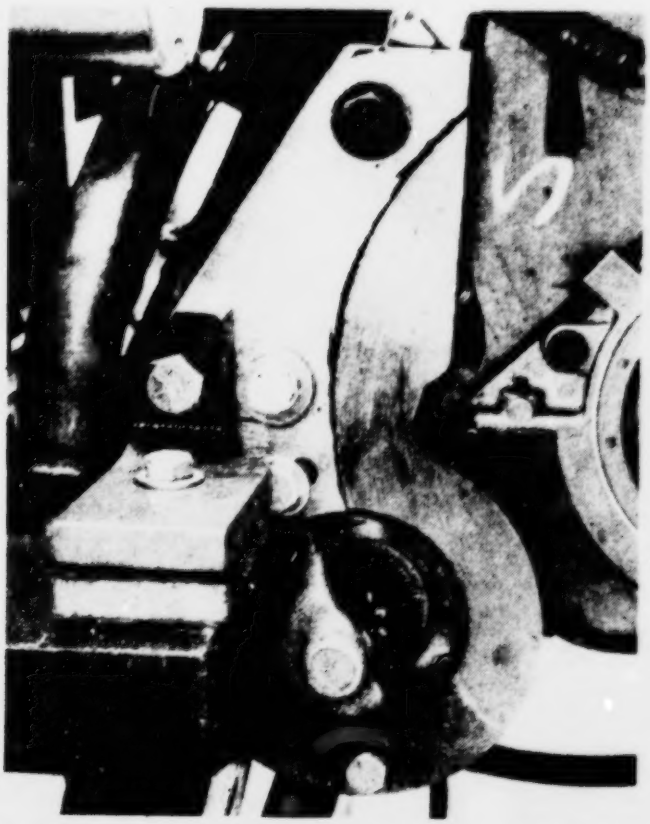


Figure 4/ Engine Mounted on Test Stand



In this photograph the flywheel has been removed to allow the specially built starter motor mounting adapter to be seen holding the starter in its operating position. The adapter replaces the missing transmission housing to which the starter is normally fastened.

Figure 5/ Starter Motor Mounted to Engine and Test Stand

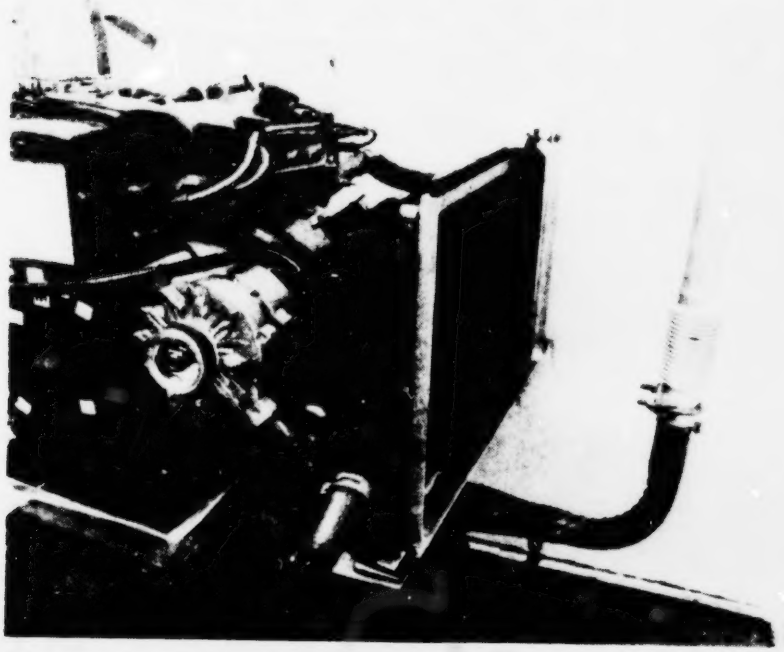
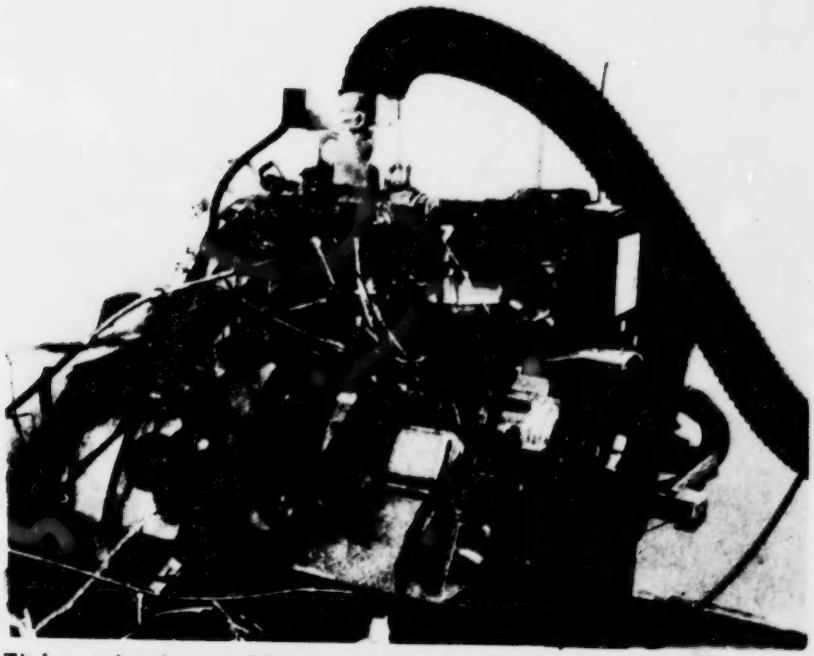


Figure 6/ Radiator Mount and Exhaust



This adapter allows the air to pass through an air box/orifice flowmeter before entering the engine via the flexible hose seen in the photograph.

Figure 8/ Brass Carburetor Inlet Adapter

4.2/ Carburetor Controls

Figures 9 to 11 show the special carburetor control and measurement devices, which include the following:

- To set and measure choke plate angle, the choke shaft of the primary carburetor barrel has been extended through a sealed bearing to a vernier adjustment assembly and locking mechanism. Provision has been made for later installation of a rotary displacement transducer.

- Stepper motors are mounted by adapters and brackets, which allows computer control of the choke and throttle positions. These motors are operational but are intended for later work, particularly warm-up testing. Consequently, they were not used for the limited shakedown tests conducted in this project.

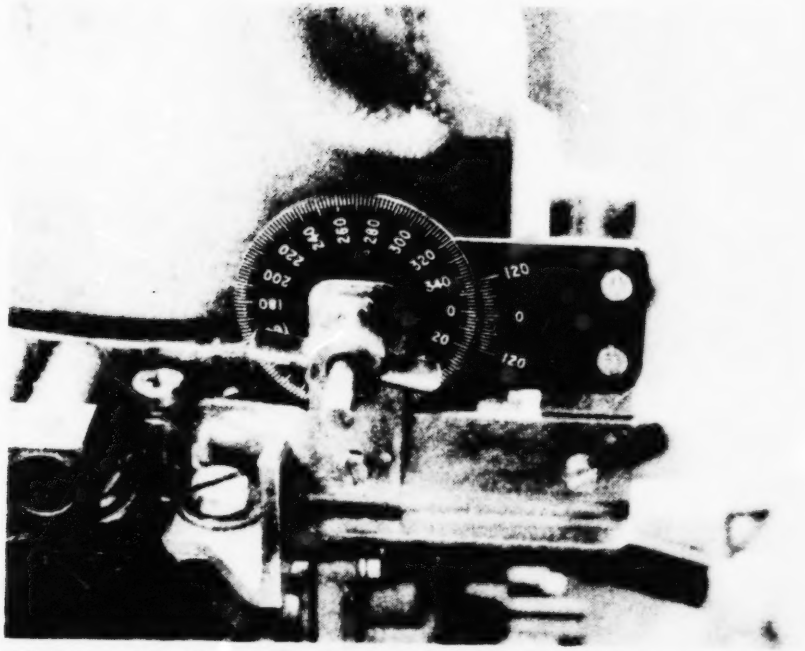


Figure 9/ Vernier Choke Position Indicator and Locking Mechanism

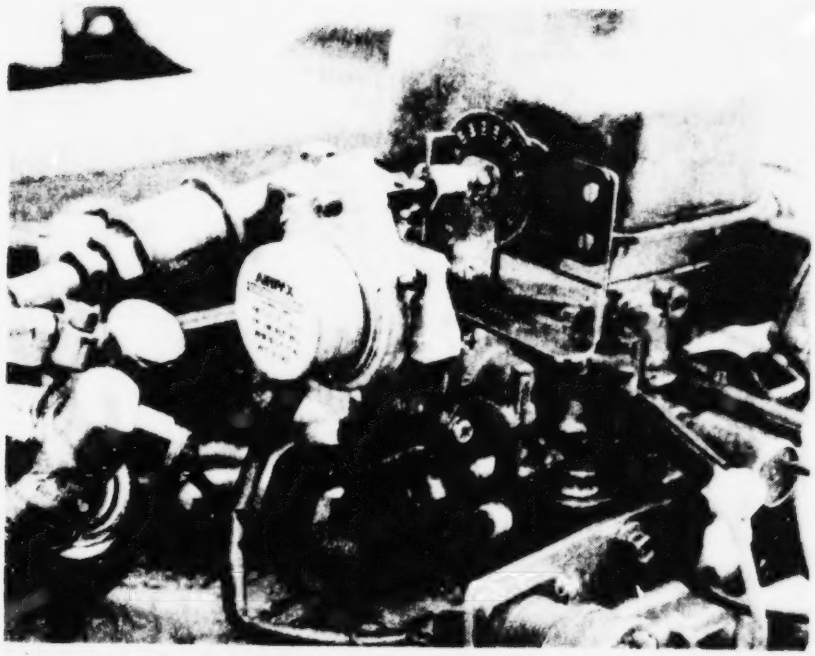


Figure 10/ Stepper Motor Choke Position Control

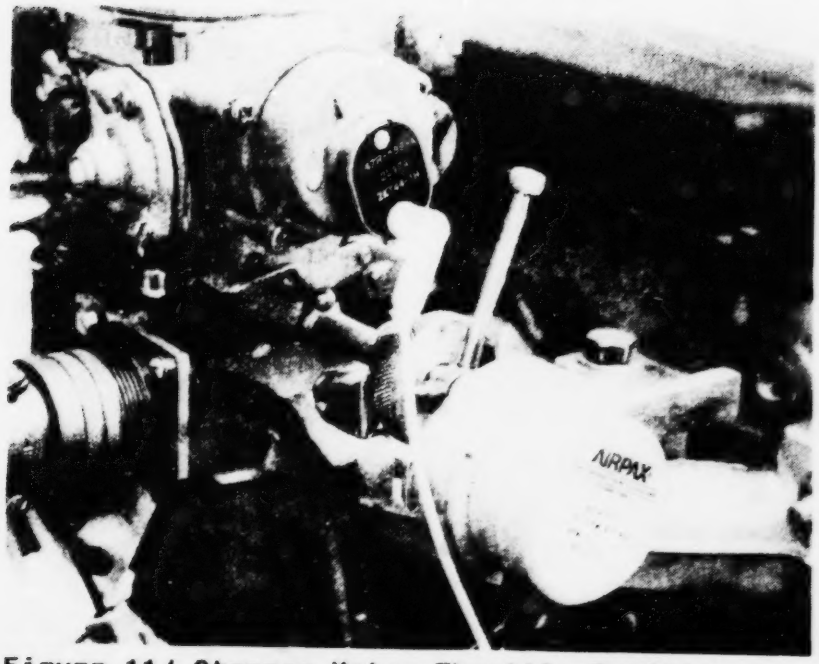


Figure 11/ Stepper Motor Throttle Position Control

5/ INSTRUMENTATION AND DATA ACQUISITION

The following basic instrumentation has been installed:

- Copper constantan thermocouples have been constructed and installed so as to measure the temperature at the following locations:
  - cold chamber air (several locations),
  - engine coolant,
  - oil sump,
  - intake manifold plenum (under electric heater),
  - engine block (sealed at the bottom of transmission housing bolt hole),
  - engine cylinder inserted through spark plug fitting and used on non-starting chill-down trials only to determine time required for complete "cold soak" at various temperatures.

- Cranking speed is measured with a dc generator and chart recorder.

- Airflow is measured with large volume air box and sharp-edged orifice connected to the carburetor inlet and located in the cold chamber. Pressure drop across the orifice (kept very low) is measured by a micromanometer located outside the chamber.

- Fuel flow is measured with a stopwatch and graduated fuel cylinder located in front of the observation window.

- Manifold vacuum is measured with an Omega absolute pressure transducer, model #PX142-015A5V.

As the basic controller to acquire the data, a small microcomputer designed especially for low cost control and data acquisition functions was purchased. It includes an eight-channel analog-to-digital converter (ADC) and has programmable output ports which can be used to drive relays, stepper motors, etc. Details of the system are included in Appendix B.

In addition to reading thermocouple and other analog data, open-loop control software was written for the microcomputer to set the positions of the choke and throttle, using the stepper motors described earlier. In its present configuration the system asks the operator to supply choke and throttle positions to be used for the test concerned. The stepper motors are then advanced to the appropriate positions by the computer. Data read by the analog-to-digital converter (ADC), choke, and throttle positions are displayed on the terminal screen. Updates and new settings are under operator control from the terminal keyboard.

Most of the potential available in the microcomputer control system was not needed for the basic shakedown testing conducted under this program; however, it forms the base required for the long-range goals involving cold running rather than just cold starting.

6/ TEST PROGRAM AND RESULTS

6.1/ Engine Wear-In

As mentioned in the introduction, there was a lengthy delay in obtaining a number of essential components missing from the original engine. Because of this, the engine could not be run until well past the original target completion date. When the probable delay in beginning testing became apparent, it was decided to make as much progress as possible in the interim by motoring the engine to break it in, using a G.E. SILPAC dynamometer. A special test stand was built for the purpose to support the engine on the dynamometer bed and permit it to be driven by means of a flexible coupling and specially constructed adapter. An oil pressure and coolant temperature monitoring system was installed, and a special cooling system was set up to substitute for the missing radiator and other stock items. An oil drain extension was made to permit oil changes while the engine was installed on the test stand, and an adapter was built to allow an existing compression gauge to be used.

Motoring was conducted with the spark plugs removed so that the driving torque directly reflected the engine friction. As piston rings and bearings seated and wore in, motoring torque decreased. A total of 20 h of run-in time was accumulated in 1 h intervals, during which revolutions per minute (rpm), motoring torque, oil pressure, and coolant temperature were monitored and logged. Motoring speed was kept in the range of 1500 to 1900 rpm. Friction power decreased progressively until approximately 10 h running had been accumulated, beyond which point no further significant changes were observed.

Before each 1 h motoring period, cylinder compression pressures were measured. Like the motoring torque, these also stabilized after about 10 h running. Cylinders No. 1, 2, and 3 always fell within a 34.5 kPa (5 psi) range, whereas the No. 4 cylinder (nearest the flywheel) was about 69.0 kPa (10 psi) below the average of the other three.

6.2/ Carburetor Calibration

After the completion of the motored break-in period, some preliminary measurements were made of the fuel/air ratio supplied by the choke at various angles. However, when the remainder of the missing induction system components arrived some months later, it was learned that the crankcase ventilation system permits additional air from the crankcase to enter the inlet manifold. The airflow measurement apparatus was therefore modified to account for this extra flow as well.

Earlier cold-starting studies conducted on a small two-cylinder engine used a fixed choke angle for any particular test run. Although the procedure worked well for that engine, it was found that a similar technique was not suitable for the engine used in the present program because it results in rich misfire once the engine begins to run. This is due to two effects:

1/ Immediately upon beginning to run, engine speed rises rapidly and airflow increases. Because the choke plate is nearly closed, the airflow rapidly approaches choked conditions across the opening; consequently, airflow rate rises more slowly than fuel flow rate, resulting in immediate mixture enrichment. This is essentially the same phenomenon as occurs in the so called "plain tube" or "elementary" carburetor discussed in most standard engine references texts [4,5]. This sudden enrichment upon firing has been observed by other workers [6].

2/ The drop in manifold absolute pressure due to higher rpm improves fuel evaporation [7]. This provides a richer vapour phase even if the overall fuel/air ratio is held constant.

Thus, a fixed choke position provides a richer mixture after the engine begins to run than it does during cranking, which is opposite to what is required. For this reason, production chokes have offset pivot shafts which allow the choke to open further against the bimetallic spring tension when airflow increases, thus leaning the mixture. Evidently, in the case of the engine used in the present work, the fixed choke settings required to cold start on methanol result in excessive enrichment after ignition, causing misfire and stalling. The choke was therefore set so as to allow it to spill open as usual, depending upon the airflow rate and the tension exerted by the bimetallic spring. This worked well but has the experimental disadvantage that choke position is noticeably affected by the changes resulting from variations in cranking speed. Consequently, fuel/air ratio cannot be ascertained by prior calibration as in the case of a choke plate clamped in a previously determined position. It is, therefore, necessary to measure instantaneous fuel flow and airflow rates for the conditions actually encountered during the starting tests. This was accomplished using an air box and burette [1,2]. The engine was cranked with the ignition disconnected but otherwise under identical conditions to the test point under study.

6.3/ Engine Cool-Down Tests

Before beginning the shakedown tests, it was necessary to determine the cold soak time required to ensure that the engine was at a uniform temperature equal to that in the cold chamber.

In addition to the normal set of thermocouples used routinely, an additional one was inserted into one combustion chamber via an airtight fitting in the spark plug hole. It was mounted so as to be in approximately the centre of the clearance volume at top dead centre. The cold chamber was then chilled down and the response of all thermocouples noted. It was found that all engine temperatures dropped uniformly and stayed within 1°C of each other. This is attributed to the combination of a relatively slow cool-down rate produced by the refrigeration system with its present low-stage evaporator valve and good air/engine heat transfer due to the high capacity fan in the cold chamber. For the temperature required for the preliminary baseline testing involved in this project, stable test temperatures were attained after 3 to 4 h of cooling.

It was anticipated that lengthy cool-down times might be required at colder temperatures to be involved in later testing on primed methanol. To reduce the time required to attain steady-state conditions inside the engine, a special coolant circulating pump and separate heat exchanger were constructed as a means of speeding up heat transfer within the block. Since this system was not required at the temperature used for the preliminary testing undertaken in this project, it was removed to permit easier access to the engine. It can easily be put into operation if required later.

6.4/ Cold-Starting Test Procedure

This procedure has been used with the shakedown experiments conducted in the project. It differs somewhat from that used in vehicle tests conducted by other workers, so some differences in results are to be expected, particularly in the cranking time required to achieve starting. One difference is that pumping the accelerator was not done because it was desired to measure actual delivered fuel/air ratio. Such pumping would normally supply fuel to the cylinders more quickly and, hence, reduce starting times.

Furthermore, since the minimum starting temperature at a given fuel/air ratio was desired, no fixed time limit was set, and up to 120 s total cranking time was sometimes used, as in Reference 8.

The detailed procedure was as follows:

1/ The engine was run to dry the cylinders of any liquid methanol from the previous unsuccessful starting attempt.

2/ The throttle was opened enough to set the automatic choke; then the throttle was locked at the fast idle cam position.

3/ The chamber was sealed and cold-soaked to achieve air, block, coolant, and oil temperatures all at within 1°C of the desired value.

4/ The battery charger was disconnected. (The battery is located outside the cold chamber and is kept fully charged.)

5/ When the electric plenum heater is being used, ignition must be turned on for 10 s. This was not done for these baseline tests.

6/ Up to eight 15 s cranking attempts were made with 5 s pauses between. This conforms to the most recent Ford instructions communicated by Shell Canada.

7/ If the engine started, it was turned off within 30 s to prevent significant heating of the block. After verification of the carburetor settings, the procedure, beginning at step 2, was repeated for a new lower test temperature.

8/ If the engine failed to start, the chamber was opened and the procedure repeated from step 1.

After determining the minimum temperature at which starting was possible for given choke conditions, the separate ignition-off cranking run was conducted under identical conditions to determine the fuel/air ratio delivered at that test point.

7/ RESULTS AND DISCUSSION

7.1/ Cold-Starting Performance of the Escort Engine

Figure 12 shows the results of the cold-starting tests on the engine when filled with pure methanol. For comparison, the data obtained previously using the small engine are also shown. Each point on the graph gives the minimum temperature at which the engine could be started for the particular fuel/air ratio provided for those conditions.

Fuel/air ratio has been expressed in the form of the fuel/air equivalence ratio Φ, defined as:

$$\Phi = f/f_{st}$$

where f = actual delivered fuel/air ratio

f_{st} = stoichiometric fuel/air ratio

Using this definition, values of Φ greater than 1 indicate rich mixtures and those less than 1 correspond to lean mixtures. Equivalence ratio is preferred to fuel/air ratio because it allows direct comparison between fuels having different stoichiometries.

Above the points shown in the figure, the engine could be started, whereas at lower temperatures, starting could not be achieved at that mixture strength (i.e., choke setting). As found in previous work using methanol in the small engine, beyond a certain richness, further fuel addition no longer improves starting. In addition to the lack of further improvement, there was also backfiring in the exhaust ducting beyond an equivalence ratio of about 8; hence, further enrichment is undesirable because of the potential for damage.

The somewhat better cold-starting performance of the Escort engine compared to the earlier results is attributable to its much higher compression ratio.

The Escort data are somewhat harder to interpret than the results for the small engine since cranking speed was not constant. Massive oil dilution resulted in cranking speeds for the lowest temperature tests which were faster than those at warmer conditions. What is not clear is to what extent the improvements at higher equivalence ratio were due to fuel effects and to what extent they were due to higher cranking speed alone. Nevertheless, as observed in previous studies, there comes a point when further enrichment provides no significant starting improvement.

It is noteworthy that the best cold-starting results reported for vehicle tests with this same engine using primed methanol are in the range of

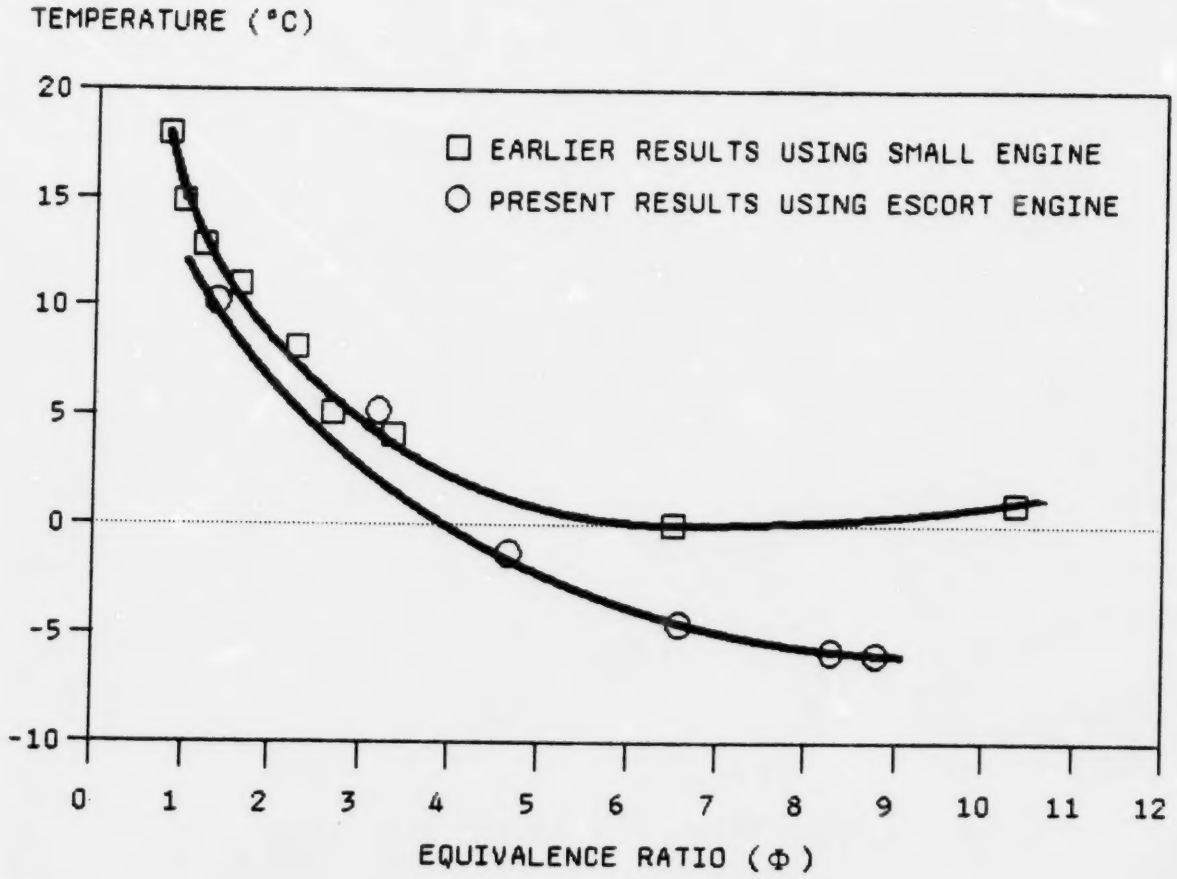


Figure 12/ Minimum Ambient Temperature at Which Starting Is Possible

-25°C. The present best result of -6°C for pure methanol is somewhat better than that reported in vehicle tests on this same engine [8].

7.2 Effect of Cranking Speed

As discussed in Section 7.1, cranking speed has a significant effect on cold-starting performance. To understand and properly interpret the observed effects, it is essential to control as many variables as possible. One of the major failings of vehicle testing such as that reported in Reference 8 and the host of similar studies published in the open literature is the inability to control cranking speed. Failure to measure or report the cranking speeds during such tests compounds the problem and makes correct interpretation difficult. The importance is that incorrect remedial measures and costly results may be the ultimate outcome.

The results of the present tests are a good example of deceptive results which can lead to specious conclusions. If cranking speed had not been measured, it would have been presumed that average cranking speed decreased with temperature and also over the period of cranking, based on the well-known behaviour of automobiles in winter. Both these conclusions would, however, have been wrong. In the tests conducted here, it was found that there is massive oil dilution by the methanol at the very rich choke settings, which give successful starting at the lowest temperature. Consequently, although basic oil viscosity is obviously increased by the lowering of temperature in the expected way, the reduction of viscosity caused by oil dilution has considerably more effect, and the net result is that cranking speed is sometimes faster at colder temperatures than at warmer ones. Table 1 illustrates this effect.

Table 1/ Effect of Oil Dilution on Cranking Speed

Oil Condition	Battery Voltage	Temperature	Cranking Speed
Fresh	13.7 V	+4°C	320 rpm
Diluted	13.3 V	-8°C	380 rpm

Thus, in spite of a lower battery voltage and higher basic oil viscosity at -8°C, cranking speed was some 16% higher than at +4°C in this particular comparison. The reduced heat losses at higher rpm result in higher temperature and better evaporation. These effects counteract, to some extent, the negative influence of colder ambient temperature.

A similar effect produces an increase in cranking speed during a given test rather a decrease. Again, this is due to oil dilution.

To unambiguously determine the effects of overall fuel/air ratio or the performance of volatility-improving additives, it is necessary to have better control over cranking speed.

8/ CONCLUSIONS

The engine is installed and running in the new cold chamber, and shake-down cold-starting tests have been conducted using pure methanol. The following changes are recommended to improve the ability of the new test facility to provide the unambiguous information needed to guide future improvements in engine and fuel characteristics:

- Install a controlled-speed cranking system, preferably able to cover a range of speeds but, in any case, able to maintain at least one constant speed in spite of torque variations.
- Add closed loop control for the stepper motors to ensure precise positioning.
- Replace the evaporator thermostatic valve so as to permit the coldest possible chamber temperature.
- Install an oil extraction and replacement system to
  - prevent damage due to oil dilution, and
  - increase experimental output by reducing maintenance downtime.

9/ REFERENCES

[1] Bardon, M.F., Rao, V.K., and Gardiner, D.P., "Cold Starting Performance of Methanol and Gasoline/Methanol Blends in Spark Ignition Engines," a report prepared for the Ontario Ministry of Transportation and Communications under the Transportation Energy Management Program, November 1983.

[2] Gardiner, D.P. and Bardon, M.F., "Cold Starting Tests on a Methanol Fuelled Spark Ignition Engine," Fuel Alternatives for Spark Ignition Engines, SP 548, Society of Automotive Engineers, Warrendale, 1983.

[3] Nichols, R.J ., "Further Development of the Methanol-Fuelled Escort," paper #830900, Proc. 2nd SAE International Pacific Conference, Tokyo, Nov. 6-10, 1983.

[4] Obert, E.F., Internal Combustion Engines and Air Pollution, Intext, New York, 1973.

[5] Lichty, L.C., Combustion Engine Processes, McGraw-Hill, New York, 1967.

[6] Anderson, R.L., "Determination of Engine Cold Start Fuel Requirements Using a Programmable Electronic Choke," SAE Paper #770107, presented at the International Automotive Engineering Congress and Exposition, Detroit, Feb. 28-Mar. 4, 1977.

[7] Bardon, M.F., "Comparison of the Cold Temperature Performance of Gasoline and Alcohols in Spark Ignition Engines," ASME paper #80-PET-17, presented at the Energy Technology Conference and Exhibition, New Orleans, Feb. 37, 1980.

[8] Nautiyal, P.C., Goetz, W.A., and Hoffman-Goetz, L., "Cold Start Wear Performance in Methanol and Gasoline Engines," SAE Paper #850215, presented at the 1985 SAE International Congress and Exposition, Detroit, Feb. 25-Mar. 1, 1985.

APPENDICES

APPENDIX A/ DESIGN OF A COLD AIR SUPPLY FOR THE ESCORT ENGINE

A.1/ Specifications

Cold Chamber:

Internal dimensions:	203.2 x 147.3 x 213.4 cm (80 x 58 x 84 in.)
Volume:	6.38 m^3

Escort Engine:

Bore and Stroke:	80 x 79.5 mm
Displacement Vol:	1.5984 L
Dry weight:	130.4 kg

Cold chamber to be designed to enable cold-starting and warm-up tests to be conducted on the engine in ambient temperatures of down to -40°C. Expected maximum speed of operation during warm-up: 2000 rpm.

A.2/ Layout Proposed

A schematic diagram of the proposed layout of the cold-testing facility is shown in Figure A.1.

The cold chamber is to be equipped with a recirculating blower with a free air delivery of approximately 0.03 m^3/s (1 ft^3/s) and a head of a few inches of water. When valve A is closed, the blower recirculates the air in the chamber. The opening of valve A is adjusted as required to admit room air to make up for engine air consumption when the engine is running. The air in the chamber is cooled by spraying liquid air into the airstream before admission to the cold chamber by the arrangement shown. Control valve B is used to vary the amount of liquid air sprayed into the airstream. The cold air enters the chamber through a number of small jets of high velocity, fanned out in a plane parallel to the top. The pipe to the inlet of the blower is connected to the bottom of the cold chamber. By this means, it is hoped that the air in the cold chamber will be well mixed and have a uniform temperature throughout. The existing evaporator fan located inside the chamber will help avoid temperature stratification. When only small quantities of liquid air have to be sprayed into the airstream, control valve B can be operated intermittently. An inclined tube manometer may be used to check whether the air pressure inside the chamber is atmospheric at all times. Temperatures recorded at a few locations in the chamber are required to make sure the chamber maintains a uniform temperature. The blower must be capable of handling air at cryogenic temperatures (-70°C).

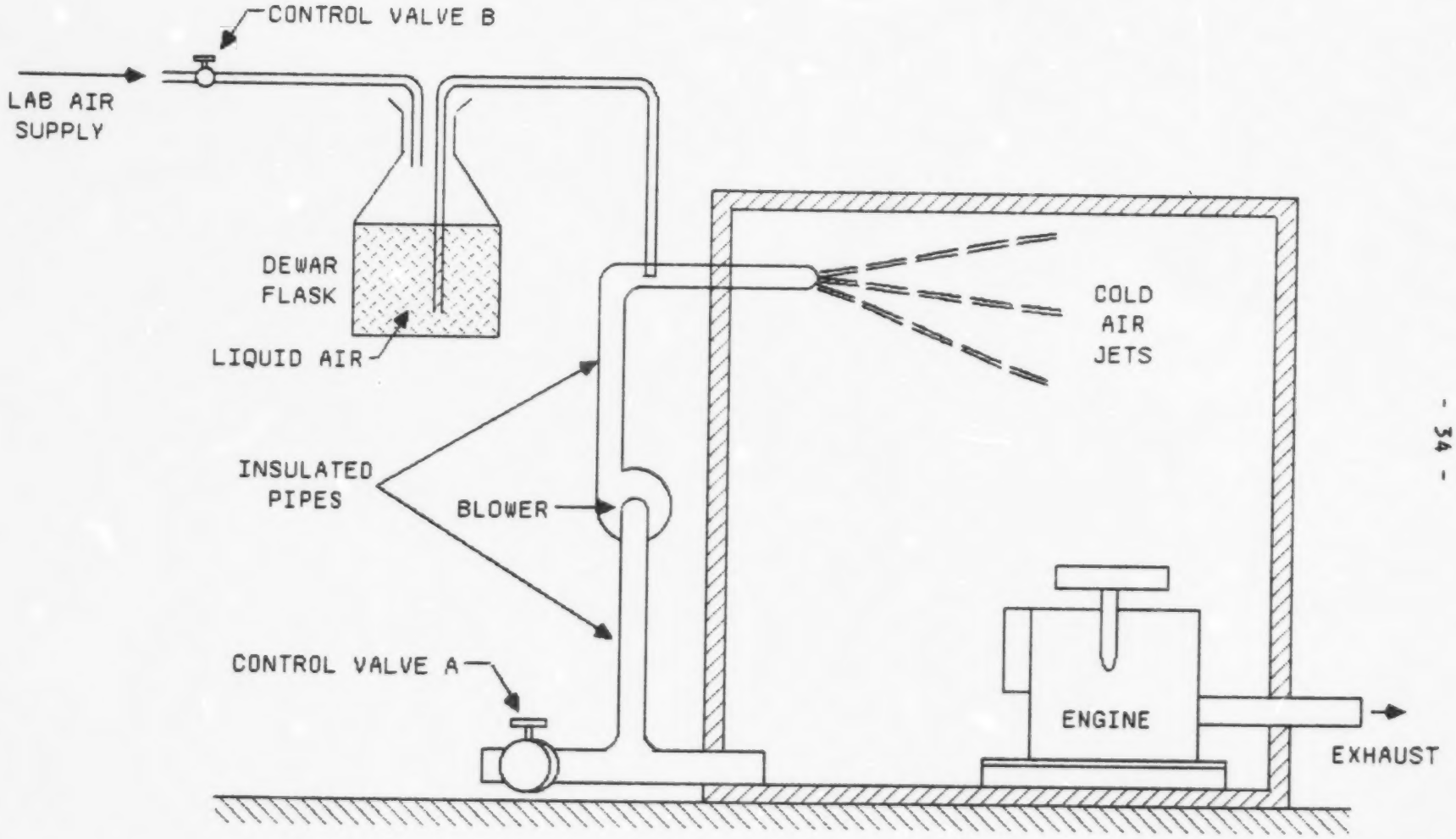


Figure A.1/ Schematic of Proposed Engine Air Supply Using Liquid Air Cooling

A.3/ Thermal and Thermodynamic Considerations

Properties of Liquid Air:

Boiling Point:	79 K
Density:	875 kg/m^3
Enthalpy of evaporation, h_{fg}:	205 J/g
Absolute visocity, μ:	80.6 x 10^{-6} N.s/m^2

(Source: CRC Handbook of Tables for Applied Engineering Science)

Specific Enthalpy of Gaseous Air at Selected Temperatures (Datum: 0 K):

	79 K	203.15 K (-70°C)	233.15 K (-40°C)	293.15 K (+20°C)
Specific enthalpy, J/mol	2207	5751	6609	8361
Specific heat, Cp, J/mol K	28.127	28.864	29.036	29.381

A.3.1/

When x grams of liquid air are evaporated for each gram of air in the airstream at an initial temperature, T_1, the final temperature of the airstream, T_2, is calculated from the equation:

$$h_{T_1} + x[h_{79} - h_{fg}] = (1+x)h_{T_2}$$

Conversely, for given T_1 and T_2, x can be calculated.

A.3.2/

Heat gain from surroundings (+20°C) to chamber through walls:

Thermal conductivity of insulation, K = 0.035 W/m.K (assumed)

Convective heat transfer coefficients (natural convection), h_1, h_2 = 5 W/m^2.K

Insulation thickness, t = 0.15 m

$$\text{Thermal resistance} = \frac{1}{h_1} + \frac{t}{K} + \frac{1}{h_2}$$

$$= 4.7 \frac{m^2.K}{W}$$

$$= \frac{20-(-70)}{4.7} = 19 \frac{W}{m^2}$$

Area of walls $\simeq 20\ m^2$

Heat gain by chamber $\simeq 380\ W \simeq 380\ J/s$

A.3.3/

Since the chamber is unlikely to be perfectly airtight, a conservative assumption is to assume that there will be one air change every hour due to leakages, etc., based on experiments with closed rooms carried out at the I.I.Sc. To compensate for this, an additional 0.3 mL/s of liquid air has to be sprayed.

A.3.4/

Time required for engine to cool down from +20°C to -40°C in an environment of -70°C:

Assumptions: Engine treated as a lumped thermal capacity losing heat to environment with a convective heat transfer coefficient equal to 5 $W/m^2.K$

Specific heat of steel, C = 450 J/kg.K

Outside surface area of engine, $A \simeq 1\ m^2$

Mass of engine, M = 150 kg

Newton's law of cooling:

$$\frac{\text{final temperature difference: } 30°C}{\text{initial temperature difference: } 90°C} = \exp\left[-\frac{hA}{MC}\tau\right]$$

$\therefore \tau \cong 4\ h$

A.3.5/

Most of the energy consumed by the recirculating blower ends up as an enthalpy increase in the airstream. This entails an additional injection rate of 1.6 mL/s of liquid air to compensate for the enthalpy increase.

A.4./ Operating Procedure

1/ Decrease chamber temperature to -70°C (requires about 0.5 mL/s liquid air to compensate for air change and heat gain from the surroundings.)

2/ Allow engine to soak for about 4 h so that it cools down to -40°C.

3/ Increase chamber temperature to -40°C.

4/ Conduct cold-start tests and warm-up tests. When the engine is running at 2000 rpm, about 6 mL/s of liquid air have to be sent in (to maintain the chamber at -40°C) along with make-up air (equal to engine air consumption).

APPENDIX B/ MICROCOMPUTER CONTROL SYSTEM SPECIFICATIONS

d5;tte.3

Processor:	Zilog Z8671 8-bit microcomputer with RAM, ROM, and I/O in a single package. Z8671 includes a 2K tiny BASIC/DEBUG resident interpreter in ROM, 144 bytes RAM, and 32 I/O lines. Systems runs at 7.3728 MHz clock rate. 1.5 μs instruction time. 6 interrupts.
Memory:	4K RAM, 2K BASIC/DEBUG ROM based interpreter, memory expandable to 62K bytes.
Input/Output:	Serial Port -- RS-232C compatible and switch selectable to 110, 150, 300, 1200, 2400, 4800, 9600 bps.
External:	16-bit address and 8-bit bi-directional data bus brought out to expansion connector.
Basic Commands:	GOTO, GO@, (USR), GOSUB, IF THEN, INPUT, LET, LIST, NEW, REM, RETURN, RUN, STOP, IN, PRINT, PRINT HEX. Integer arithmetic: +, -, /, *, and BASIC can call machine language subroutines for increased execution speed; allows complete memory and register interrogation and modification.
Power Supply:	+ 5 V @ 5 A + 12 V @ 4 A 12 V @ 500 mA
Analog/Digital Converter:	8 channel 1 kHz sampling rate independent of number of channels in use 8-bit resolution 0 - 10 V or ± 5 V input signal range